

CONTRIBUTION TO OPTIMISE AN INTELLIGENT MECHANIC-ELECTRIC CONVERSION OF CLEAN ENERGY (WIND)

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Abstract. It is presented an applied brief study concerning the possibility for optimal obtaining an electrical power of 1 MW for a mean wind energy flux of 0.7 kW/m^2 (a wind speed of 10.5 m/s), using a high performance modern three-blade wind turbine having dimensional limits like the Danish wind turbine V63-1.5 MW (for wind speed $v_{\infty} = 16 \text{ m/s}$), equi-power and equi-speed, using the NACA-23015 lift airfoil. The optimisation is presented by an original analytical relation between wind speed, lift surface area and the proposed power that minimise the fluid energy loss and the axial push force, assuring the maximum mechanic-electric conversion.

Keywords: wind energy, wind turbine, power coefficient, lift coefficient, resistance coefficient

1. MODERN CONCEPTS CONCERNING (ABOUT) THE TYPICAL AXIAL WIND TURBINE

Research and development projects like Bonus 750 kW, Enercon E-66, Nordic 1000, Vestas V63-1.5 MW seems typical and modern. The last has been assembled on the experimental field at Tjaereborg-Denmark and connected to electric network. The project is based on the experience obtained from the previous assemblage of two wind turbines, serially produced: V 39-500 kW and V42-600 kW.

The project VESTAS V 63-1.5 MW is typically a very modern. The wind turbine has been assembled on the experimental field from Tjereborg, Denmark and connected at the electric network. The project is based on the know-how of two previous projects series made, V39-500 kW and V42-600 kW.

The European Commission has financed the research connected with the assemblage of high power wind turbines within the framework of many multinational projects. The projects referring to the research and development stage has constitute JOULE program and the demonstrative projects including innovative technical elements and associated measures for strategy, dissemination and promoting which has outruned this stage, has been included in the program THERMIE. It is noticed the research-development projects as Bonus 750 kW, Enercon E-66, Nordic 1000 (Gotland- Sweden).

The globalisation, decentralisation and decarbonisation representing main tendencies of each future energetic investment, wind energy has an major impact in all theses tendencies.

VESTAS 1.5MW is a three blades wind turbine with horizontal axle, variable step and the rotor placed upstream of the tower. The rotor diameter is 63 m and produces a nominal electric power of 1500 kW. The height at the rotor hub is 60 m (fig.1).

Rotor blades have an advanced light construction and especial profiles. The basic structure is a laminar material made of glass fibre and epoxy resin. The blades-hub attachment is made aided by a light flange by aluminium, jointed by the stratified material from glass fibre.

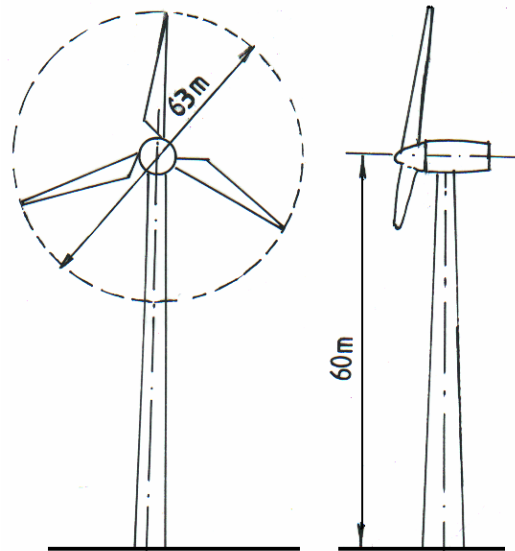


Fig. 1: Overall dimensions of the VESTAS V63-1.5MW system

The rotor hub is cast by steel. For blade step control, the hub is provided with ball bearing and a mechanism.

The system of blade step control is characterised by a separate variation of the step. Thus, the system provide a security enhance in the case of damage and also the possibility of an operating optimisation.. This solution permits the blade angle set to the optimum value every moment, for power and also for the noise level (very small). The system for the step is acted by a hydraulic servo-motor situate in nacelle.

The rotor axle and the system of bearings compose an assembly mounted on a base plate with help of two separated ball bearings.

The gear is of planetary type (single stage) and parallel (two stages) and a multiplying ratio of 72.

The electric generator is of asynchronous type with the possibility of speed variation by a system with optimal slip. The rotor of generator can slip until 10% from the nominal speed. The slip power is dissipated in a system of resistors connected to the rotor. The system is controlled in a manner as only power tops due to gust of wind can initiate the hub slip. The efficiency decreasing is limited. This conception of the generator permits to maintain the nominal power during high winds, independent of the air density and temperature. It assures an uniform production of energy and an important decrease of stress.

The nacelle of the wind turbine consists in a compact frame of resistance made by welded steel. The cover is made of a material semi-stiffened with glass fibre.

The tower is a conical tube of steel having the height of 60 m. The conception of the wind turbine Vestas 1.5 MW includes two different dimensions of the rotor diameter: 57m and 63m, function of the wind regime in the place where it is assembled (the rotor with the little diameter corresponds to the regime with higher velocity). The wind turbine V63-1.5 MW is realised in modularised sections, permitting for example the transport of the nacelle in standardised containers, without the necessity of especial equipments for the transport from the fabrication place to the emplacement place. Also, the tower segments weight is not over 25t each.

2. SOME BASIC FORMULAS

The specific velocity, defined as the ratio between the tangential blade velocity $u = \omega \cdot R$ and wind velocity v_∞ is expressed by:

$$\lambda = \frac{\omega \cdot R}{v_\infty} = \frac{u}{v_\infty} [-]. \quad (1)$$

The upstream incident fluidic power is:

$$N_\infty = A \cdot \frac{\rho \cdot v_\infty^3}{2} [\text{W}] \quad (2)$$

and the wind energy flux density is:

$$\frac{\rho \cdot v_\infty^3}{2} \left[\frac{\text{W}}{\text{m}^2} \right], \quad (3)$$

ρ being the air density and A – the surface area described by the blades.

The power coefficient (efficiency) is:

$$C_P = \frac{N}{N_\infty} = \frac{2 \cdot N}{\rho \cdot A \cdot v_\infty^3} [-], \quad (4)$$

with the turbine mechanical power:

$$N = M \cdot \omega [\text{W}], \quad (5)$$

M being the moment and ω - the angular speed.

The turbine overall efficiency:

$$\eta_{ov} = \eta_{gear} \cdot \eta_{el.gen.} \cdot \eta_{el.tr} \cdot C_P [-] \quad (6)$$

and the suitable electric generator power:

$$N_{el} = \eta_{ov} \cdot N_\infty [\text{W}] \quad (7)$$

with efficiencies: gear, $\eta_{gear} = 0.95...0.99$; electric generator, $\eta_{el.gen.} = 0.94...0.97$; electric transformer: $\eta_{el.tr.} = 0.98...0.995$.

For Vestas turbine blades are indicated the airfoil NACAxxx/FFA-W3, unknown by us.

3. THE OPTIMAL WIND TURBINE

It is presented further on an applied brief study about the possibility for optimal obtaining (with minimal fluidic energy loss at the air passing through rotor) an electric power, $N_{el} = 1 \text{ MW}$, wind turbine mechanic power, $N = 1.08 \text{ MW}$, moment, $M = 450 \text{ kN} \cdot \text{m}$, maximum speed, $n_{\max} = 22.9 \text{ rev/min}$, maximum angular speed, $\omega_{\max} = 2.4 \text{ s}^{-1}$, maximum peripheral velocity $u_{\max} = 75.5 \text{ m/s}$, constant speed of the electric generator for a nominal wind velocity of 10.5 m/s in a wind velocity range $v_{\infty} = 8 \dots 20 \text{ m/s}$. It is considered the rotor diameter $2R = 63 \text{ m}$, surface area $A = 3117 \text{ m}^2$, using a known airfoil for blades: NACA-23015.

For the proposed airfoil there are known the laws of variation with the incidence angle, $i \leq 10^\circ$ for aerodynamic coefficients: lift coefficient C_z and resistance coefficient, C_x

$$C_z(i) = 0.1 + 0.11 \cdot i; \quad (8)$$

$$C_x(i) = 0.007 + 0.0055 \cdot [C_z(i) - 0.2]^2. \quad (9)$$

The optimal angle is $i_{opt} = 6^\circ$, for which $C_z(i_{opt}) = 0.76$ and $C_x(i_{opt}) = 8.73 \cdot 10^{-3}$. The air density is $\rho = 1.2 \text{ kg/m}^3$.

It is presented further the optimal wind velocity calculus for the proposed three-blades rotor. Thus, it necessitates the power consumption:

$$N_x = F_x \cdot v_{\infty} = C_x(C_z) \cdot S \cdot \frac{\rho \cdot v_{\infty}^3}{2} [\text{W}] \quad (10)$$

is minimum.

The power obtained by lift is:

$$N_z = F_z \cdot v_{\infty} = C_z \cdot S \cdot \frac{\rho \cdot v_{\infty}^3}{2} [\text{W}]. \quad (11)$$

Thus, it obtains the coefficient C_z from relation (11) and it is replaced in (9). After numeric calculus it obtains:

$$C_x = 7.22 \cdot 10^{-3} + 5.5 \cdot 10^{-3} \cdot C_z^2 - 2.2 \cdot 10^{-3} \cdot C_z [-] \quad (12)$$

and

$$N_x = 3.77 \cdot v_{\infty}^3 - 224 \cdot v_{\infty} + \frac{1.1 \cdot 10^5}{v_{\infty}} [\text{W}]. \quad (13)$$

The condition for the minimum ($N_x \rightarrow \min$) is:

$$\frac{\partial N_x}{\partial v_\infty} = 11.31 \cdot v_\infty^2 - \frac{1.1 \cdot 10^5}{v_\infty^2} - 224 = 0 \quad (14)$$

and it results $v_{\infty, opt} = 10.5 \text{ m/s}$, with optimum lift surface: $S_{opt} = 870 \text{ m}^2$.

The character of maximum or minimum for that point can be tested by the second derivative:

$$\frac{\partial^2 N_x}{\partial v_\infty^2} = 22.62 \cdot v_\infty + 2.2 \cdot 10^5 \cdot v_\infty^{-3} > 0, \quad (15)$$

therefore the solution of the equation (14) represents a minimum ($N_x = \min$).

Table 1 presents results of calculus, the independent variable being $v_\infty \in [8 \text{ m/s}, 20 \text{ m/s}]$.

Generally, it is recommended the domain $\lambda = 3 \dots 7$.

Table 1. Results of optimisation calculus

$v_\infty \left[\frac{\text{m}}{\text{s}} \right]$	8	10.5	12	15	20
$\frac{\rho \cdot v_\infty^3}{2} \left[\frac{\text{kW}}{\text{m}^2} \right]$	0.306	0.697	1.035	2.03	4.8
$N_\infty \text{ [MW]}$	0.95	2.17	3.24	6.30	14.90
$N_{el} \text{ [MW]}$	0.392	1.0	1.43	2.16	3.72
$N_x \text{ [kW]}$	13.9	12.4	13.0	16.76	31
λ	9.4	7.15	6.25	4.58	3.44
C_P	0.445	0.5	0.477	0.37	0.27
η_{ov}	0.413	0.463	0.440	0.342	0.250

Figure 2 presents the characteristic of power (dimensionless), $\eta_{ov}(\lambda)$ calculated for the proposed wind turbine, using the follow values of efficiency: $\eta_{gear} = 0.97$; $\eta_{el.gen.} = 0.96$; $\eta_{el.tr.} = 0.99$.

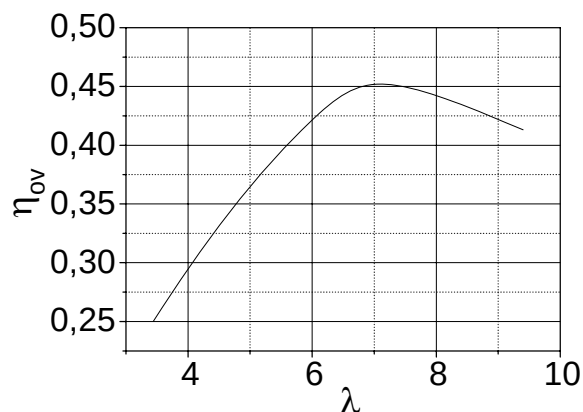


Fig. 2: Characteristic of system power

The wind turbine is recommended for a nominal wind velocity $v_{\infty} = 10.5$ m/s, (that corresponds to a medium wind potential relatively modest, characteristic to our country), with a conversion realised at maximum values for C_P and η_{ov} .

4. REFERENCES

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